

[0010] In 1989, in U.S. Pat. No. 4,855,595, Blanchard taught a focusing method based on time-varying electric fields.

[0011] In 1992, Avida et al. U.S. Pat. No. 5,235,182 found that inhomogeneous fringe fields along the mobility drift cell could be used to reduce the loss of ions from the edge of the mobility drift cell and hence to reduce the size of mobility instruments. The inhomogeneous fringe fields were generated by simply increasing the thickness of the field-generating ring electrodes such that the ratio of electrode thickness to inter-electrode gap could be manipulated to provide the fringe fields.

[0012] In 1993 Thekkadath (U.S. Pat. No. 5,189,301) taught a cup shaped electrode to generate a focusing field. This field configuration compares to the Vehnelt cylinder used in non-collisional ion optics.

[0013] In 1996 Gillig et al. published a magnetic field to confine the ions in a small beam in order to increase the ion transmission from the mobility section into a mass spectrometer.

[0014] In 1999 Gillig used a periodic configuration of focusing and defocusing fields in order to increase the ion transmission from the mobility section into the MS section, as discussed above. This field configuration compares to a technique used in non-collisional ion optics where series of focusing and defocusing lenses are used to confine ion beams in large ion accelerators [Septier, p. 360].

[0015] Nonlinear electric fields have also been introduced to ion mobility drift cells to focus ions to a detector as presented in U.S. Pat. No. 5,189,301 to Thekkadath utilizing a cup electrode and U.S. Pat. No. 4,855,595 to Blanchard using nonlinear fields for the purpose of controlling ions, trapping ions in a potential well to normalize drift differences and increase sensitivity. All of these methods have drawbacks associated with their construction and ease of implementation. Therefore, it is the object of this invention to reduce or eliminate disadvantages and problems associated with prior art ion mobility instruments.

[0016] Additionally, improvements at the drift tube/MS interface are described. The use of radio frequency focusing using rf quadrupoles, the use of microchannel aperture plates, and the pre-selection of parent ions for mass analysis by collision-, surface-, or photo-induced dissociation is described. Use of these methods in the instrumental platforms and the corresponding analytical methods represents a further improvement afforded by the invention over the prior art.

SUMMARY OF THE INVENTION

[0017] In a specific embodiment of the present invention there are methods and apparatuses for separating and analyzing ions comprising an ionization source to generate ions, an ion drift cell coupled to said ionization source, in which the ions are separated according to their mobility and which comprises electrodes for transporting and focusing the ions, the focusing uses a superposition of periodic field focusing and hyperbolic field focusing. A detector is coupled to the ion drift cell for detection of the ions.

[0018] In a closely related embodiment, instead of separating and analyzing the ions, the invention may be used as

an ion transport instrument, useful in any application where the transport of ions for an ion source to a desired location is required.

[0019] In another embodiment, of the present invention there are methods and apparatuses for separating and analyzing ions comprising an ionization source to generate ions, an ion drift cell coupled to said ionization source, in which the ions are separated according to their mobility and which comprises electrodes for transporting and focusing the ions, the focusing uses a combination of periodic field focusing and hyperbolic field focusing. A detector is coupled to the ion drift cell for detection of the ions. Preferably, this combination is a sequential combination of the fields.

[0020] In a closely related embodiment, instead of separating and analyzing the ions, the invention may be used as an ion transport instrument, useful in any application where the transport of ions for an ion source to a desired location is required.

[0021] In a further embodiment, methods and apparatuses analogous to those described above utilize purely hyperbolic field focusing. These embodiments use sliding tube electrodes and hyperbolic-shaped electrodes.

[0022] In specific embodiments of the separation and analysis methods and apparatuses described above, the detector may be a mass spectrometer, preferably a time-of-flight mass spectrometer (TOFMS), and more preferably, a TOFMS having a flight tube positioned orthogonally with respect to the ion mobility drift tube cell. In other embodiments, there are specific interfaces between the mass spectrometer and the drift cell. These include known interfaces, such as microchannel aperture plates and radio frequency focusing interfaces. For microchannel aperture plates, the preferred embodiment uses a bundle of capillaries. The radio frequency interface may be a combination of a radio frequency electric field and a direct current electric field. Other embodiments use known fragmentation means for fragmenting ions after mobility separation and before mass analysis. These include collision-induced dissociation (CID), surface-induced dissociation (SID), and electron impact dissociation or a combination thereof. Alternatively, there may be a radio frequency quadrupole to focus the ions after fragmentation.

[0023] Specific embodiments use electrodes of a variety of configurations and conformations. Cone-shaped (conical) electrodes, thick plate electrodes with holes, cup-shaped electrodes are examples of some embodiments. In one specific embodiment of electrodes with holes, multiple holes are used in order to focus several parallel beams of ions, thereby resulting in "multi-channel" ion mobility. The electrodes may be arranged in a variety of ways. They may have equal or unequal distance between them, they may have equal or unequal hole diameters, and they may have unequal potentials applied to them. An electrode stack is used in one embodiment; preferably this stack contains seal rings, positioning rings and/or positioning tubes that act to position the electrodes or seal the drift chamber.

[0024] The above-described embodiments possess further specific embodiments related to the ionizing beam and its associated devices. Preferably, the ionizing beam is a laser, but it may be any known, useful ionization source. In one embodiment, one or more mirrors are used to redirect the ionizing beam to the sample to be ionized. This allows